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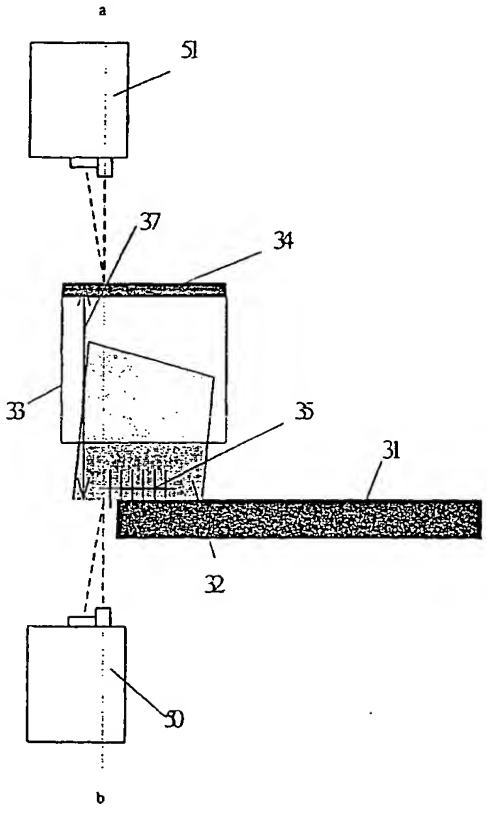
[Continued on next page]

(54) Title: A METHOD AND APPARATUS FOR INLINE MEASUREMENT OF MATERIAL REMOVAL DURING A POLISHING OR GRINDING PROCESS



(57) Abstract: Apparatus for inline measurement of material removal during a polishing or grinding process, said apparatus comprising: a. a substantially circular rotatable grinding or polishing pad (1); and b. a sample holder (5); and c. a sample (32) with a top, a bottom and one or more side surfaces; wherein the sample holder (5) is arranged to hold the bottom surface of the sample (32) in contact with the pad (1) and the sample holder (5) being connected to a moving device to move the sample (32) to a position at least partially over the rim of the pad (1), during at least a part of the process, said apparatus further comprising a detecting device for sampling the distances between a reference mark (34) and a target area (35) in the sample (32) and a plane defined by the bottom surface of the sample (32) during the process.

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A method and apparatus for inline measurement of material removal during a polishing or grinding process

Field of the invention

The invention relates to materialographic grinders and polishers and more particularly to inline measurement of material removal on rotary grinders or polishers for preparation of samples to micron or submicron precision. Inline measurement means that the measurement is performed during/simultaneously with the grinding or polishing process.

Background of the invention

Materialographic grinders and polishers are used intensively for preparation of raw material and for preparation of samples to microstructural analysis. For example submicron precision polishing is used for preparation of silicon wafers which are useful for chip fabrication. Automated grinding is widely used as a shaping process of solid materials, for example for final shaping of sintered advanced ceramic components and various metallic precision parts. Polishing and grinding are also used in quality control and failure analysis for materialographic examination. In all these cases fast, reliable, automated inline measurement of material removal is essential for the end user.

State of the art

The grinding and polishing process takes place on a rotary grinding or polishing apparatus. A micrometer screw as described in US5816899, Hart et al, may control

concerns on how to keep the measurement system tidy during measurement. Furthermore, the measurement system uses diffraction of white light for the determination of the film thickness, which is not suitable for non-transparent materials.

Another way of measuring the material removal is to follow the vertical displacement of the polishing head during the polishing. This may for example be done by a linear variable differential transformer or by a laser displacement sensor. To realise high precision the system must be highly mechanically stiff, which is expensive and difficult to achieve for lab-size equipment. Otherwise the vibration of the polishing system during operation together with the flexibility of the polishing pad reduces the precision of these methods.

Consequently there is a need for a method and an apparatus which can be used for measurements on a sample during a grinding or polishing process, and which method and apparatus are easy in use and able to make measurement of removal of material with high precision.

The object of the present invention is to provide a system for inline measuring material removal during a grinding or polishing process.

A second object of the present invention is to provide a system for measuring material removal which is less sensitive to mechanical vibration of the grinding or polishing system than the prior art techniques.

A third object of the present invention is to provide a system for measuring material removal which is less

In one aspect the present invention relates to an apparatus for inline measurement of material removal during polishing or grinding of a specimen. Such an apparatus comprises

- a circular rotatable grinding or polisning pad;
- a sample holder
- a sample or specimen with a top surface, a bottom surface and one or more side surfaces. Normally the sample has a shape of a cylinder with a circular cross section and thereby having one side surface. Alternatively the sample may have a triangular or quadrangular etc. cross section and thereby having three or more side surfaces. Preferably the top surface and the bottom surface are planar.

In the apparatus according to the invention the sample holder is arranged to hold the bottom surface of the sample in contact with the grinding or polishing pad and preferably the sample holder is connected to a moving device which during the grinding or polishing process moves or slides the sample to a position at least partially over the rim of the grinding or polishing pad. The moving device preferably is an arm in connection with a mechanism and driving aggregate e.g. an electro motor, which will cause the arm to move. Moreover the apparatus comprises a detecting device for sampling the distances between a reference mark and a target area in the sample and a plane defined by the bottom surface of the sample during the grinding or polishing process and at the position where the sample is at least partially over the rim of the grinding or polishing pad. The detecting device is connected to a device for storing and/or comparing said distances, and the detecting device sends

micrometer or alternatively a combination of two laser displacement sensors.

The size of the sample or specimen may vary considerably. Typically, the specimens have a circular cross section but any geometry may be used as long as the part of the specimen constituting the bottom surface and used for the measurement of the aforementioned distance has sufficient size for the measurement to be made. The specimen should preferably be at least approx. 1 cm over the rim of the polishing or grinding pad when the measurement takes place. However, by carefully positioning the measurement system, smaller amounts or areas of sample can be acceptable.

In order to achieve acceptable measurements it is preferred that the sample diameter is at least 20 mm, preferably 25 to 50 mm and more preferably 30 to 40 mm.

Very large samples like for example silicon wafers may easily be measured by the system described in this invention.

In a preferred embodiment of the invention the sample holder is highly important for use as reference mark. In this embodiment the sample holder must have a well-defined upper reference plane, edge or point. The geometry of the reference plane depends on the type of sweeping and optional rotation of the sample and/or sample mover. For the preferred embodiment with the scanning laser micrometer the important fact is that when the sample holder is seen from the side it should form a sharp upper line for the measurement of the aforementioned distance.

arm connected to a driving mechanism e.g. a computer operated electro motor.

More than one sample may be treated simultaneously. In a preferred embodiment of the apparatus the sample holder may hold more than one sample. Any number of samples may be treated simultaneously, but the preferred numbers are 1, 3, 4, 5, 6, 8 or 12 samples at one time.

In a preferred embodiment of the apparatus according to the invention the device for storing and/or comparing the measured or detected distances during the grinding or polishing process is a computer. For the skilled person it is clear that the same computer can be utilized for receiving and storing data from the detecting device e.g. a scanning laser micrometer, and calculate and compare the data and simultaneously control the entire apparatus or selected functions like for example the moving device or the polishing pad.

The system as described above is preferably used for preparation of materialographic samples. However, the system may also be used for other applications. One important application where the invention is highly useful is preparation of silicon wafers.

Another aspect of the present invention relates to a method of grinding or polishing a sample or silicon wafer on a substantially circular rotating grinding or polishing pad, which method comprises the steps of:

a. selecting an area of interest in the raw material to form the sample or alternatively select a silicon wafer as a sample to be treated

k. grinding or polishing the bottom surface of the sample until the plane defined by the bottom surface is congruent/coincident with the target area while controlling the removal of material by measuring the distance between the plane defined by the bottom surface and the reference mark and comparing the measured distance with the stored reference distance

l. Stop the grinding or polishing of the top surface when the distance between the plane defined by the top surface and the reference mark is equal to the stored reference distance.

By use of the method according to the invention it is possible to grind or polish a sample with very high precision.

The target area may be a target plane or a target mark/spot or target line.

The reference mark may also be a plane line or spot.

In a preferred embodiment a planar surface which is substantially parallel to the surface of the grinding or polishing pad is used as reference mark, preferably the planar surface is the upper part of the sample and/or the sample holder. In this embodiment the reference mark can be established in an easy and uncomplicated way.

Preferably more samples are placed in the sample holder and grinded or polished simultaneously. It is preferred that 3 to 12 samples are placed in the sample holder and are treated at the same time in order to save time in the process.

Moreover the method according to the invention is used for grinding or polishing silicon wafers.

The invention will now be described in further details with reference to a drawing, which illustrates some embodiments of the invention. The drawing comprises the following figures:

Fig. 1 shows top-view of set-up with single sample holder and radial sweeping.

Fig. 2 shows top-view of another embodiment with sample holder with 3 samples or 1 sample and 2 dummies.

Fig. 3 shows top-view of another embodiment with single sample holder and semi-circular sweeping.

Fig. 4 shows side-view of set-up.

Fig. 5 shows examples of top reference planes.

Fig. 6 shows the set-up using two displacement sensors.

Fig. 7 shows a sketch of the set-up for the feasibility test.

Fig. 8 shows screen prints from sensitivity test.

In Figure 1 a top-view of the set-up with a single sample holder is seen. The sample (5) is sweeped forward and backwards towards the centre (2) of the polishing or grinding pad (1). On Figure 1A the sample is passing over the rim of the polishing or grinding pad and the height from the end face of the sample is polished and the

In Figure 2 simultaneous treatment of 3 samples is shown as an example but the moving device or the sample holder may be designed to other numbers of samples with 3,4,6,8 and 12 being the preferred number of samples. 2 samples may be treated simultaneously, but in that case one dummy will most likely be treated along with the samples since 3 pieces tend to be more geometrical stable than 2 pieces.

In Figure 3 another preferred embodiment for the sweeping of the sample is shown. Here, the sample in the sample holder (5) is moved along a fraction of a circular path (10) with centre (11) outside the polishing or grinding pad by a moving device. This path takes the sample between near the centre of the polishing or grinding pad to partly over the rim of the polishing or grinding pad.

Sweeping of the sample with the moving device serves several causes. Primarily, it levels out the wear of the polishing pad, thereby yielding a more cost-effective preparation. Secondly, the sweeping reduces formation of half moon shape - an edge effects on the sample. Moreover, the sweeping facilitates a more even scratch pattern.

In Figure 4 the principle of the measurement is shown. The sample (32) is placed in the sample holder (33) and the combined sample and sample holder is placed on the polishing pad. Figure 4A and 4B both show the sample during the measurement when the sample is over the rim of the polishing or grinding pad. The target of the polishing is inside the sample. The target may be a

the 90° turned set-up (with a vertical polishing plane) - used in some high precision applications - may likewise be used.

In Figure 5 various examples of reference planes are shown. In Figure 5A, the reference plane is a line. The line may consist of a sharp edge or a rod. The sharp edge is easier to manufacture but the rod is less sensitive to wear and misuse of the sample holder. A sample holder with just one sharp edge is most suited for a set-up where the sample swept radially or along a fraction of a line but not rotated round the axis of the sample centre. In Figure 5B, a sample holder has two crossing lines. These lines may likewise for example be sharp edges or rods. In Figure 5B, a sample holder with two crossing lines is shown but sample holders with more crossing lines are also feasible. In Figure 5C, the reference plane is a flat top. This type of sample holder is easy to manufacture and is clean, however, with such a sample holder the reference plane may be hard to realign if disturbed.

The reference planes described in Figures 5A, 5B and 5C is only to be considered as examples of embodiments of the reference plane and not as a complete list of ways to form a reference plane on the sample holder.

In figure 6 an example of a set-up using two laser displacement sensors is shown. The laser displacement sensors (50) and (51) are aligned to reduce the sensitivity towards vibration and tilting of the sample holder. In figure 6 the laser displacement sensors are aligned along an imaginary line a-b. The distance (37) between the reference mark (34) and the plane defined by

The pause from the laser beam lattice was broken until the beginning of the measurement was varied between 100 - 600 ms and the measurement time was varied between 1 - 30 ms.

The optimum self-timing parameters for the investigated set-up was a pause of 500 ms after the laser beam lattice was broken followed by averaging for 20 ms. With these parameters the standard deviation for 20 measurements cycles was 1.1 µm.

The optimum self-timing parameters depend on the sample diameter, and the nature of the sweeping. However, reasonably standard parameters may be pre-programmed.

Example 2: Sensitivity towards mechanical vibration of the experimental set-up

The sensitivity towards mechanical vibration of the system is crucial for the feasibility of the system since it is an inline system.

The sensitivity towards mechanical vibration of the system was tested using a LS-5041, Keyence, placed on a Labopol-6, Struers. A steel cylinder with parallel end faces was placed in the measuring field of the LS-5041. The sample height was measured with the Labopol-6 deactivated and with the Labopol-6 running with 100 rpm. The LS-5041 was run in normal mode meaning that the height of the cylinder was measured continuously.

In Figure 8 screen prints of the results are shown. The results show that the measured height of the sample is 18.873 mm (without vibration, Figure 7A) and 18.874 mm

obstruction for the laser beam and hence influence the measurement. This problem may easily be overcome by mounting a splash shield in front of the laser transmitter and receiver.

5

substantially parallel to the surface of the grinding or polishing pad, preferably said reference mark is placed on or in connection with the sample and/or the sample holder.

3. An apparatus according to claim 1 or 2 wherein the target area is constituted by a plane, a line, a spot/mark/point.

4. An apparatus according to claims 1 or 2 or 3 wherein the detecting device to detect the distance between the reference mark and a plane defined by the bottom surface of the sample is a scanning laser micrometer or a combination of two laser displacement sensors.

5. An apparatus according to any of claim 1 to 4 wherein the sample diameter is at least 20 mm, preferably 25 to 50 mm and more preferably 30 to 40 mm.

6. An apparatus according to any one of claims 1 to 5 wherein the sample holder comprises a goniometric mechanism for three-dimensional adjustment of the sample prior to the polishing or grinding process.

7. An apparatus according to any one of claims 1 to 6 wherein the apparatus further comprises a moving device for moving or sliding the sample holder over the surface of the grinding or polishing pad, said moving device is connected to the sample holder and capable of moving or sliding the sample holder in a desired pattern e.g. a radial, a circular, or a rotating pattern.

8. An apparatus according to any one of claims 1 to 7 wherein the sample holder is adapted to contain more than

one sample, preferable the sample holder is adapted to contain 3 to 12 samples and more preferably 3 to 6 samples.

9. An apparatus according to any one of claims 1 to 8 wherein the device for storing and/or comparing the measured or detected distances during the grinding or polishing process is a computer.

10. Use of an apparatus according to claims 1 to 9 for preparation of materialographic samples.

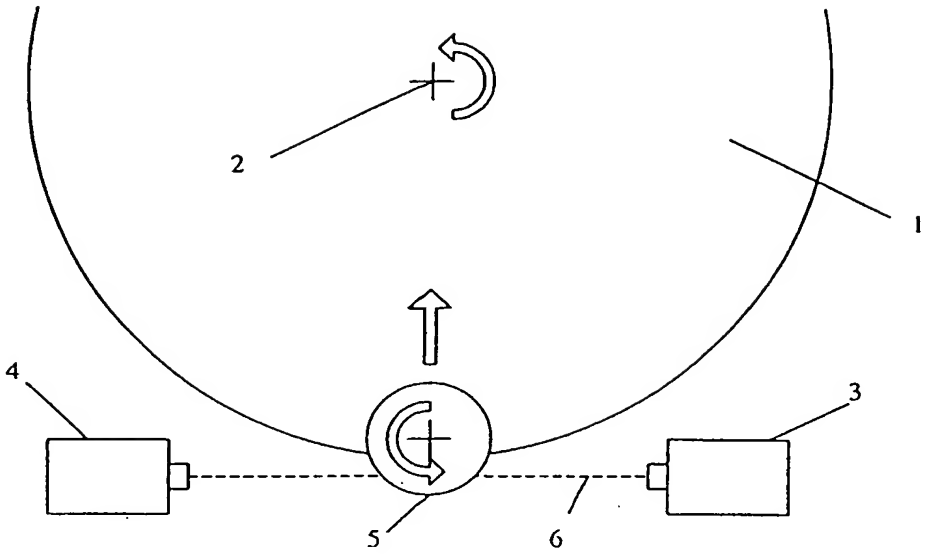
11. Use of an apparatus according to claims 1 to 9 for polishing of wafers.

12. A method for grinding or polishing a sample or silicon wafer on a substantially circular rotating grinding or polishing pad, which method comprises the steps of:

i. selecting an area of interest in the raw material to form the sample
ii. optionally resizing the raw material for example by cutting
iii. optionally mounting the raw material in a resin and cure the resin to form a sample with a top surface, a bottom surface and at least one side surface, in which said an area of interest is substantially within area near the bottom surface
iv. placing the sample in a sample holder
v. identifying a reference mark
vi. identifying a target area in the sample

Fig. 1

A)



B)

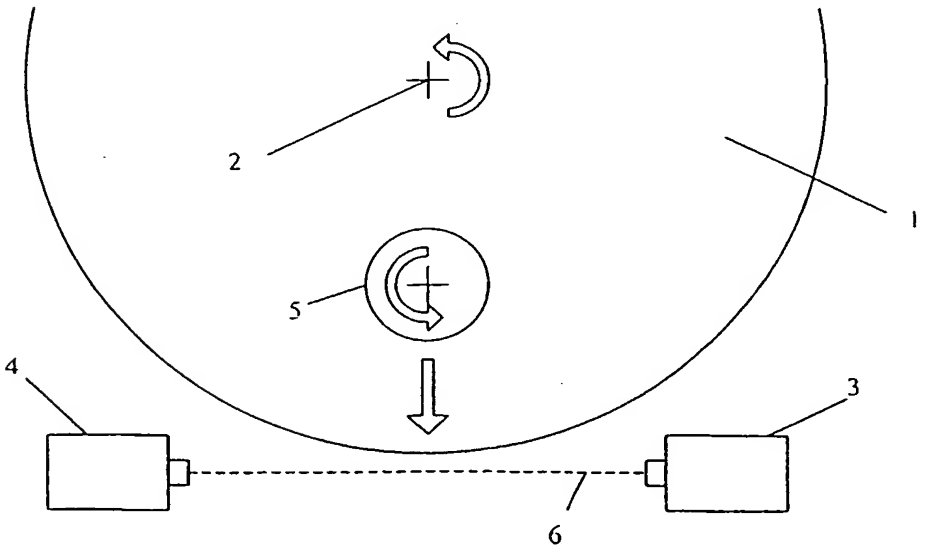


Fig. 2

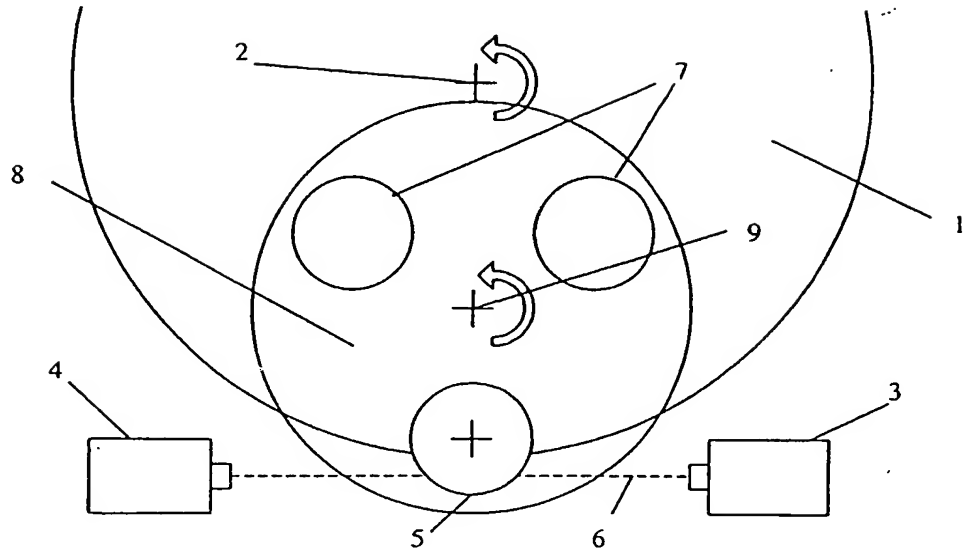


Fig. 3

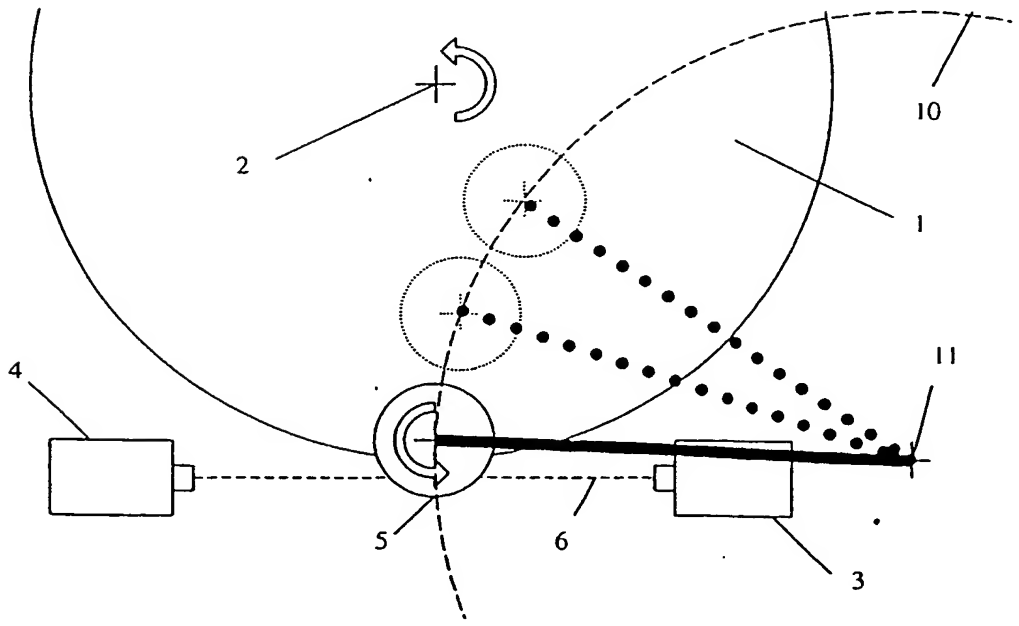
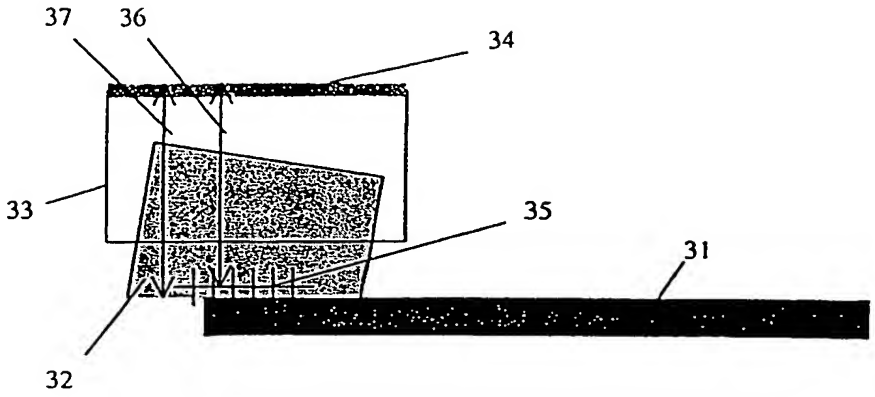


Fig. 4

A)



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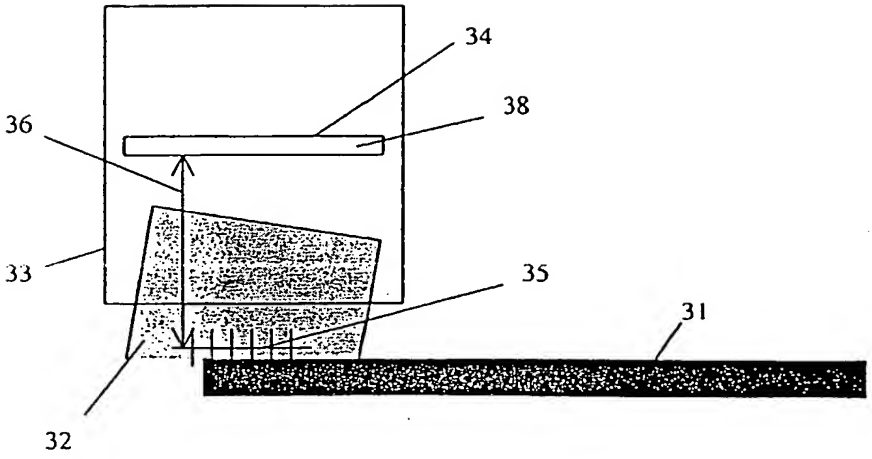


Fig. 5

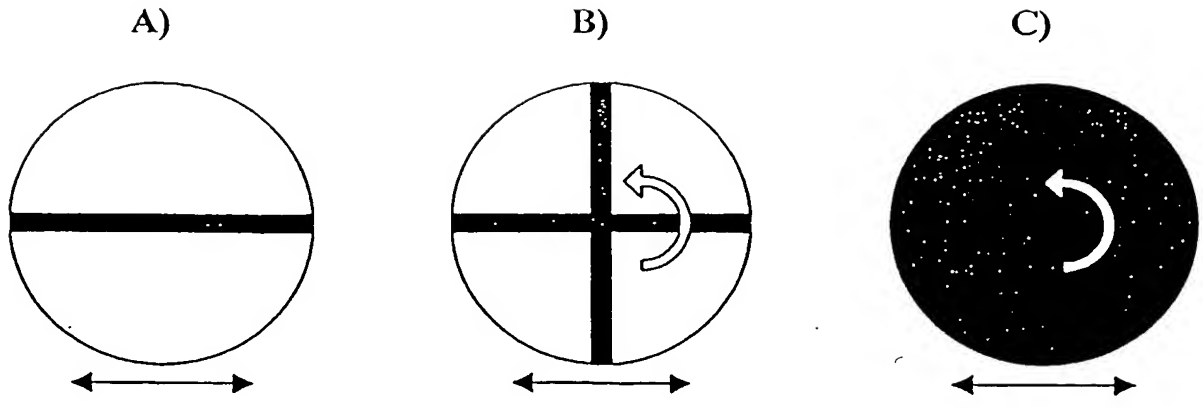


Fig. 6

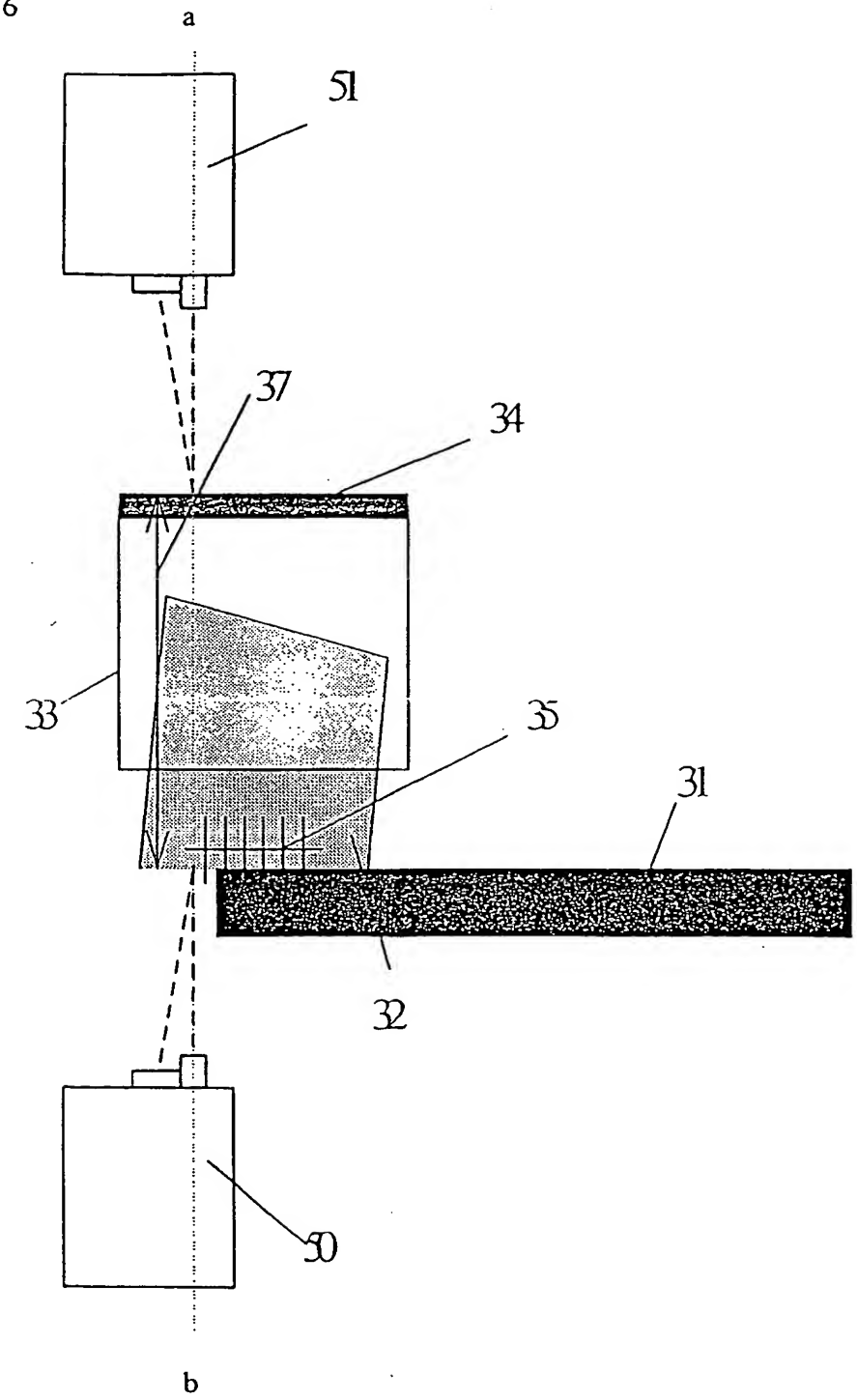
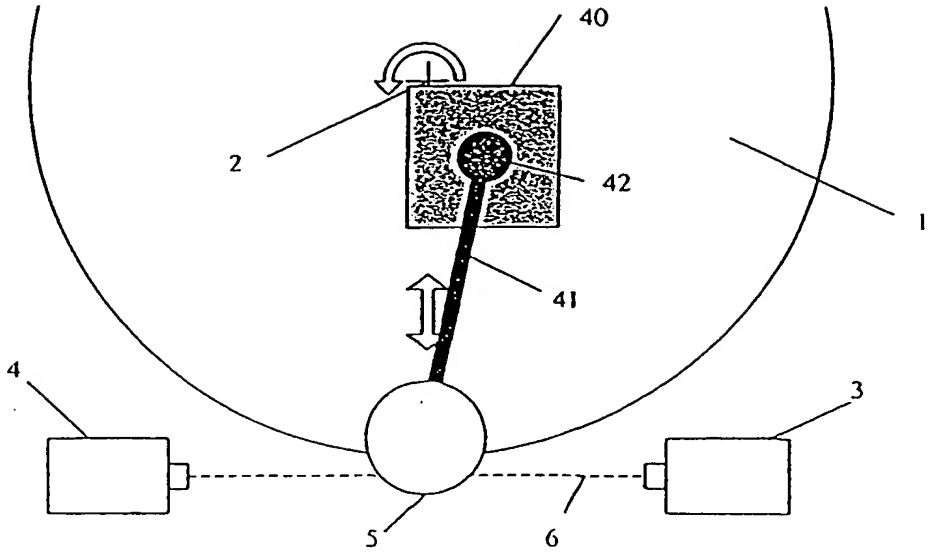
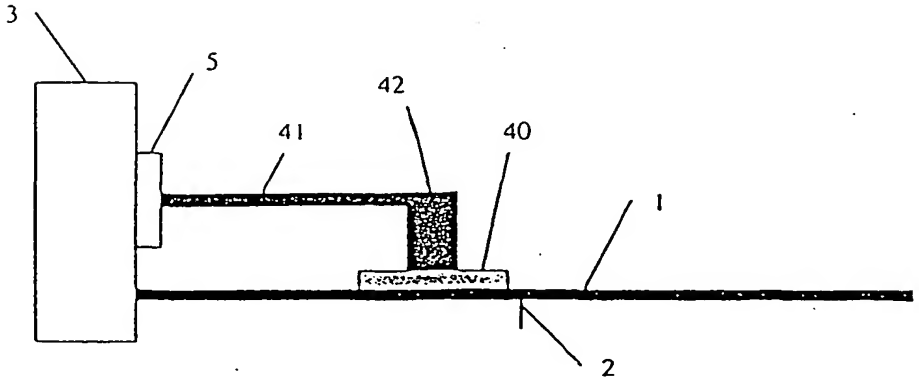


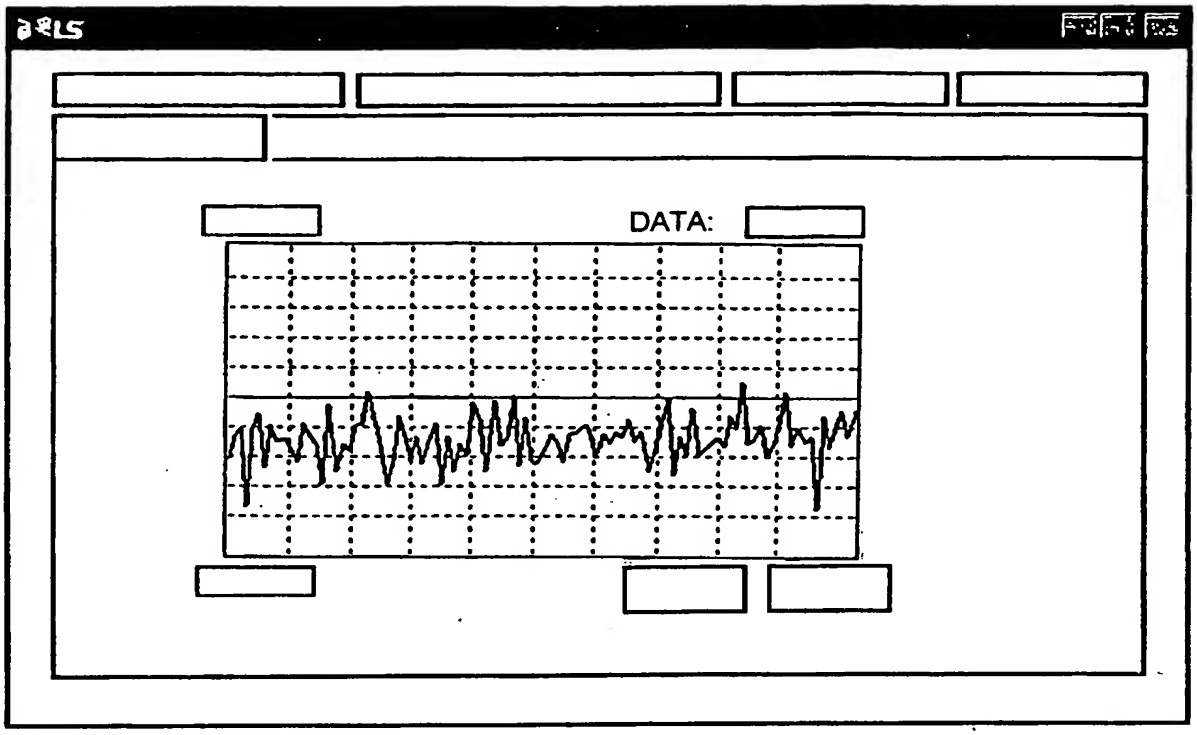
Fig. 7



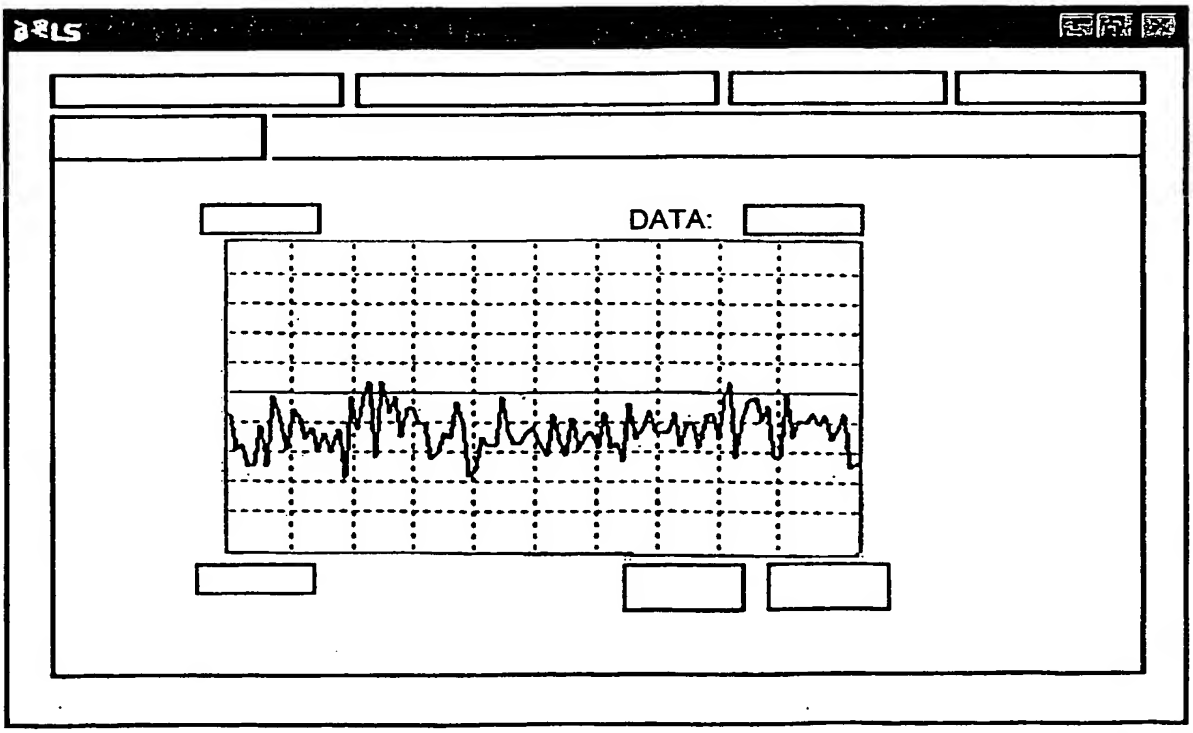
B)



A)



B)



INTERNATIONAL SEARCH REPORT

International Application No
PCT/DK 02/00610

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B24B37/04 B24B49/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B24B G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2001/023167 A1 (YANO HIROYUKI ET AL) 20 September 2001 (2001-09-20) abstract paragraph '0024! - paragraph '0029! figures 1,2	1,4,7, 9-12, 15-19
A	US 6 208 425 B1 (SANDHU GURTEJ SINGH ET AL) 27 March 2001 (2001-03-27) column 3, line 26 -column 4, line 50 figure 2	1-3,7, 9-12, 16-19

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2002	21/11/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Schultz, T

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/DK 02/00610

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2001023167 A1	20-09-2001	JP 2001225261 A	21-08-2001
US 6208425 B1	27-03-2001	US 5936733 A	10-08-1999
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		ZA 9510553 A	02-07-1996
US 6213844 B1	10-04-2001	NONE	

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P200101285WO	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/DK02/00610	International filing date *(day/month/year)* 20.09.2002	Priority date *(day/month/year)* 24.09.2001
International Patent Classification (IPC) or both national classification and IPC B24B37/04		
Applicant STRUERS A/S et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the opinion
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
10.04.2003	12.09.2003
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Telephone No. +49 89 2399-

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/DK02/00610

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, Pages

1-21 as originally filed

Claims, Numbers

1-19 as originally filed

Drawings, Sheets

1/6-6/6 as originally filed

2. With regard to the **language,** all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).

   ☐ the language of publication of the international application (under Rule 48.3(b)).

   ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:

   ☐ the claims, Nos.:

   ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-19
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-19
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-19
	No:	Claims	

2. Citations and explanations

see separate sheet

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

The nearest prior art for the subject-matter of independent claims 1 and 12 is described in US2001/023167.

Inventive step:
a. Measuring the reference distance from the target area in the sample to the reference mark and storing it.
b. Controlling the removal of material by measuring the distance between the plane defined by the bottom surface and the reference mark and comparing it with the stored reference distance.

Technical effect:
Method and apparatus are easy in use and able to make measurement of removal of material with high precision.

Hence, claims 1 and 12 meet the requirements of Art. 33 PCT.
The dependent claims 2-11 and 13-19 describe preferred embodiments of the invention and therefore they also meet the requirements of Art. 33 PCT.